Fertiliser Price Risk Management in Swedish Winter Wheat Production:

An Evaluation of Behaviourally Adjusted Contracts

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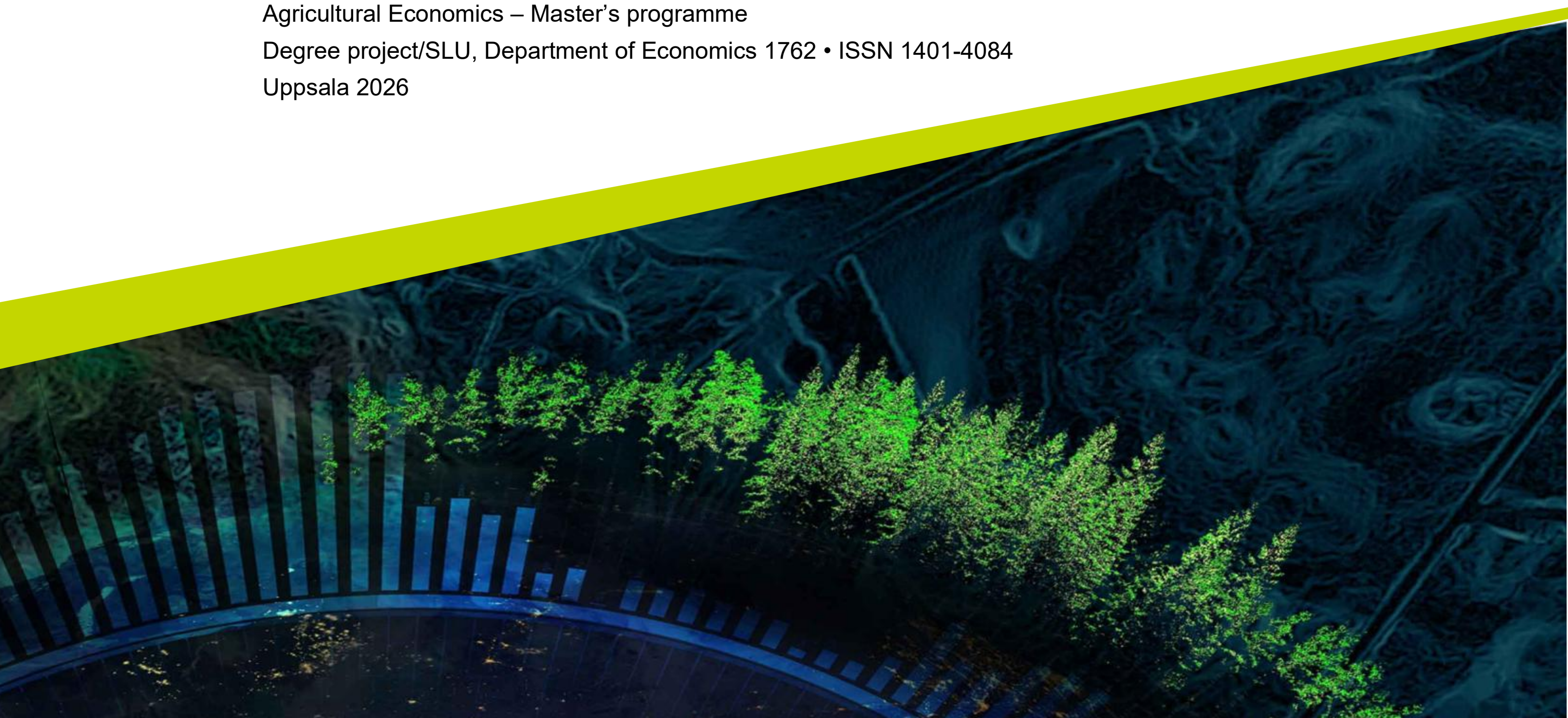

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Abstract

This thesis evaluates whether behaviourally adjusted fertiliser price contracts are attractive risk-management tools for Swedish farmers growing winter wheat. The analysis combines simulated regional yield data with wheat and calcium ammonium nitrate price data to compare different fertiliser procurement strategies. Contract attractiveness is evaluated under Expected Utility Theory and Cumulative Prospect Theory and under both broad and narrow framing. The results suggest that regional differences in Sweden affect expected profit levels and production risk, but do not substantially change the relative ranking of the contract alternatives. Instead, contract attractiveness appears to be shaped by the decision framework and framing assumption. Under Expected Utility Theory broad framing, the forward contract performs best across regions. This suggests that the flexibility of the adjusted contracts does not compensate for the premium paid when the fertiliser decision is evaluated as part of total farm profit. Under narrow framing, adjusted contracts become more favourable relative to the forward contract. This is likely because they allow farmers to benefit from lower fertiliser prices while limiting exposure to high prices. However, this relative advantage does not necessarily imply that adjusted contracts are attractive in absolute terms. Under Cumulative Prospect Theory, adjusted contracts are generally unattractive under broad framing but are preferred under narrow framing. However, the sensitivity analysis shows that their performance remains sensitive to the assumed behavioural parameters. The findings suggest that behaviourally adjusted fertiliser price contracts are not consistently superior risk-management tools for Swedish winter wheat farmers. Their attractiveness depends more on behavioural assumptions and decision framing than on regional production conditions.

Keywords: Agricultural risk management, fertiliser procurement, input price volatility, Expected Utility Theory, Cumulative Prospect Theory, decision framing

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Abbreviations

Abbreviation	Description
CAN	Calcium Ammonium Nitrate
CE	Certainty equivalent
CPT	Cumulative Prospect Theory
EPIC	Environmental Policy Integrated Climate model
EUT	Expected Utility Theory
MATIF	Marché à Terme International de France
NUTS	Nomenclature of Territorial Units for Statistics
QVAR	Quantile Vector Autoregression
SEK	Swedish Krona
VAR	Vector Autoregression

1. Introduction

Agriculture operates in an inherently uncertain environment shaped by changing weather and volatile input and output prices. Sweden’s dependence on imported inputs, such as fertiliser, increases its vulnerability to disruptions in agricultural commodity markets. Furthermore, due to Sweden’s geography, production conditions and yield levels differ substantially between regions, meaning that the same input price shock may have different consequences depending on where production takes place (Gren et al. 2024).

Recent policy developments and geopolitical instability may increase uncertainty about future nitrogen fertiliser prices. This includes higher duties on nitrogen fertilisers from Russia and Belarus, the introduction of the Carbon Border Adjustment Mechanism, and the reduction in free allocations under the EU Emissions Trading System, all of which may affect fertiliser markets and future input costs (European Commission: Directorate-General for Agriculture and Rural Development 2025). For farmers, such developments may make future fertiliser costs more difficult to anticipate, which can increase the relevance of price risk management tools.

One way farmers can manage this type of uncertainty is through financial risk-management instruments, such as forward contracts, futures, options, and price insurance, which are designed to reduce farmers exposure to volatile input and output markets (Hardaker et al. 2015). Under standard models of decision-making under risk, these instruments – if reasonably priced – should be attractive to risk-averse producers because they can stabilise farm income. In practice, however, adoption in agriculture remains low despite these potential benefits (Spada et al. 2026). This gap between the theoretical attractiveness of risk-management instruments and their limited uptake suggests that farmers decisions may not be fully explained by standard models of decision-making under risk.

Empirical evidence suggests that farmers choices under risk are not always well described by Expected Utility Theory (EUT). This may be linked to behavioural features such as loss aversion, probability weighting, and reference dependence. Alternative frameworks, such as Cumulative Prospect Theory (CPT), incorporate these features and may therefore provide a more realistic representation of how farmers evaluate risky choices and risk-management instruments (Bocquého et al. 2014; Rommel et al. 2023; Finger et al. 2024). This is particularly relevant for fertiliser price contracts, where farmers may evaluate premiums, avoid losses, and missed gains relative to a reference point rather than only through expected profit. Against this background, this thesis examines whether the attractiveness of behaviourally adjusted fertiliser price contracts differs across Swedish regions, decision theories, and framing assumptions.

An important starting point for this thesis is the report by Spada et al. (2026), which develops and evaluates a behaviourally adjusted fertiliser price contract designed to account for farmers behavioural preferences. Using a stochastic simulation for a representative West German farm, the report compares the attractiveness of the contract under Expected Utility Theory and Cumulative Prospect Theory, as well as under broad and narrow framing. The results show that the adjusted contract appears attractive under standard EUT only when decisions are framed as part of total farm profit, whereas under CPT it is unattractive regardless of framing. These findings suggest that the appeal of fertiliser price risk-management instruments depends not only on contract design, but also on how farmers evaluate risk and potential losses.

Spada et al.'s (2026) analysis is based on a representative West German farm. It therefore remains an open question whether the results are specific to that production context or whether they also apply in countries with different yield levels, production risks, and regional heterogeneity. Sweden provides a useful case because production conditions differ between regions, while fertiliser and wheat prices are shaped by broader market dynamics that affect all regions. This makes it possible to examine whether regional differences in production conditions alter the attractiveness of behaviourally adjusted fertiliser price contracts.

The aim of this thesis is to assess whether behaviourally adjusted fertiliser price contracts are attractive risk-management tools for Swedish farmers and whether this attractiveness differs across regions, decision-making frameworks and framing assumptions. This thesis adapts the framework from Spada et al. (2026) to Swedish winter wheat production and evaluates whether regional differences in yield and production risk affect the attractiveness of such contracts.

2. Literature review

The traditional literature on agricultural price-risk management has been based on Expected Utility Theory and the mean-variance framework. In this framework, hedging decisions are modelled as a trade-off between expected returns and risk, with farmers risk preferences determining the attractiveness of risk-management instruments (Spada et al. 2026). Risk-averse farmers are therefore assumed to be willing to accept lower expected profits in exchange for reduced exposure to price risk (Boyd & Bellemare 2020). Empirical studies generally support the relevance of risk aversion in agriculture, as European farmers have often been found to exhibit risk-averse behaviour (Iyer et al. 2020; Garcia et al. 2024). In the specific context of fertiliser management decisions, Moritz et al. (2026) show that most studies also focus primarily on risk preferences within an Expected Utility framework, while broader behavioural factors remain largely overlooked. This literature provides the benchmark prediction that risk-averse farmers should value instruments that reduce profit variability, even if these instruments reduce expected profit.

Despite the theoretical advantages of financial hedging instruments such as forward contracts, futures, and options, their adoption among farmers remains relatively limited (Assefa et al. 2017; Spada et al. 2026). Empirical evidence suggests that these instruments are not always primarily viewed as tools for reducing price risk. For example, Michels et al. (2019) find that farmers intentions to use commodity futures contracts are more strongly driven by motives to increase received prices than by motives to reduce price risk. These findings suggest that standard risk-based models may not fully explain adoption behaviour.

Behavioural models have therefore been used to explain why farmers observed choices may deviate from the predictions of Expected Utility Theory. Cumulative Prospect Theory (CPT) is particularly relevant because it incorporates reference dependence, loss aversion, and probability weighting, which are absent from standard EUT (Tversky & Kahneman 1992). In an agricultural hedging context, Mattos et al. (2008) incorporate probability weighting and loss aversion into a futures hedging model and find that hedge ratios are influenced more by probability weighting than by loss aversion or conventional risk aversion. Furthermore, Babcock (2015) show that CPT can help explain observed crop insurance choices, but mainly when insurance is framed narrowly as a stand-alone investment rather than as part of broader farm risk management. Under this narrow framing, predicted coverage choices are much closer to observed farmer behaviour. Moreover, in an experimental study by Bocquého et al. (2014), using lottery based field experiment data from French farmers, they find that farmers are risk averse under EUT. However, they also find that farmers choices are better explained under CPT. Their results indicate that farmers exhibit both loss aversion and probability weighting, with farmers being approximately twice as sensitive to losses as to equivalent gains and farmers also tend to overweight outcomes that have a low probability of happening. Rommel et al. (2023) who replicate Bocquého et al. (2014) across 11 European farming systems confirm that CPT generally provides a better fit than EUT for farmers lottery-choice behaviour. Together the two studies provide empirical support for using CPT as a behavioural framework when analysing farmers risk preferences.

Recent work has also examined alternative behavioural approaches to farmers decision-making under risk. Mattsson et al. (2025) introduce tri-reference point (TRP) theory to agricultural economics and examine whether farmers evaluate risky outcomes relative to multiple income thresholds rather than a single reference point. In this framework, outcomes may be judged against a minimum requirement, a typical or status quo level, and an aspirational goal. Their results provide supportive but nuanced evidence for this perspective, showing that farmers tend to respond more strongly to outcomes linked to minimum requirements and goals than to deviations around the status quo.

Spada et al. (2026) apply EUT and CPT to a behaviourally adjusted fertiliser price-risk management contract and compare broad and narrow framing. They find that the adjusted contract appears attractive under EUT only when evaluated as part of total farm profit, while it is unattractive under narrow framing and under CPT regardless of framing. Their findings show that the attractiveness of fertiliser price-risk management instruments depends not only on contract design, but also on the assumed decision model and framing.

Swedish agriculture is exposed to several types of risk that vary across regions. Evidence from survey-based research shows that farmers attitudes towards risk differ depending on the source of uncertainty, such as price, production, policy, and environmental risks, indicating that risk management decisions are context-specific and influenced by available tools (Lagerkvist, 2005). Empirical studies also document substantial regional variation in production risk. Yield variability and the probability of severe yield losses differ across crops and counties (De Toro et al. 2015). These differences are partly explained by temperature and soil properties (Kirchmann et al. 2020), while extreme weather events affect regions differently, with southern Sweden more sensitive to summer drought and northern regions more affected by excess water and winter conditions (Sjulgård et al. 2023). Taken together, this literature suggests that Swedish farmers do not face a single uniform risk environment. This makes regional heterogeneity important when evaluating the potential attractiveness of financial risk-management instruments across Swedish regions.

3. Theoretical background

3.1. Decision-making under risk: EUT and CPT

In an Expected Utility Theory framework, farmers are assumed to compare risky alternatives according to the utility they provide. A useful way to express this comparison is through the certainty equivalent. The certainty equivalent is the guaranteed payoff that gives the decision-maker the same utility as a risky option. In other words, the decision-maker is indifferent between receiving a risky option and receiving the certainty equivalent for sure. The difference between the expected payoff and the certainty equivalent is the risk premium, which is the amount the decision-maker is willing to give up from the expected payoff in order to avoid risk (Pratt 1964). Using the mean-variance approximation, the certainty equivalent can be written as:

$$\mathrm{CE} \approx E(x) - \frac{\delta}{2} Var(x) \ (1)$$

where x is the payoff of a risky outcome in absolute terms and $E(x)$ is the expected payoff. $Var(x)$ is the variance and δ is the coefficient of absolute risk aversion. This means that, for a given expected payoff and variance, a farmer with stronger risk aversion will assign a lower certainty equivalent to the risky outcome. Similarly, for a given risk aversion, a more uncertain payoff also lowers the CE.

Tversky and Kahneman (1992) developed Cumulative Prospect Theory (CPT) as an alternative framework for decision making under risk. CPT assumes that individuals evaluate outcomes relative to a reference point rather than in terms of final wealth. Outcomes above the reference point are perceived as gains, while those below are perceived as losses. Unlike Expected Utility Theory (EUT), CPT assumes that losses are weighted more heavily than gains of the same size.

$$v(x) = \begin{cases} (x)^{\alpha}, if x \geq 0 \\ -\lambda(-x)^{\beta}, if x < 0 \end{cases} (2)$$

Here v(x) represents the value function where x is the outcome relative to the reference point. If x≥ 0, the outcome is treated as a gain and if x<0 it is treated as a loss. The parameters α and β determine the curvature of the value function, where α applies to gains and β applies to losses. If α and β are below one, the value function exhibits diminishing sensitivity. The parameter λ is greater than one and reflects the idea that losses have larger effect compared to equally sized gains. The overall value of a risky prospect is then given by:

$$V = \sum_{i \epsilon G} \pi_i^+ v(x_i) + \sum_{j \epsilon L} \pi_j^- v(x_j) (3)$$

where V is the overall prospect value, x_i and x_j are possible outcomes, G denotes the set of gains, L the set of losses, π_i^+ and π_j^- are decision weights for gains and losses. These are derived from transformed cumulative probabilities meaning that CPT uses subjective decision weights rather than objective probabilities. The transformation is represented using Prelec (1998) probability weighting function:

$$w(p) = \exp(-(-lnp)^\gamma) \ (4)$$

The function transforms the objective probability p into a probability weight $w(p)$, which is used to construct the decision weights π_i^+ and π_j^-. The parameter γ determines how strongly probabilities are distorted. If $\gamma < 1$, small probabilities are given more weight than their objective probability, while high probabilities are given less weight. CPT therefore provides a framework for understanding decisions in which reference dependence, loss aversion and the perception of nonlinear probabilities play a central role.

3.2. Decision framing: broad and narrow

The way a farmer frames a risk-management decision may affect how the same contract is evaluated. Tversky and Kahneman (1981) show that how a decision is mentally framed can affect preferences and choices. Barberis et al. (2006) define narrow framing as the tendency to evaluate risky choices in isolation rather than as part of a broader portfolio. In an agricultural context, Babcock (2015) and Dalhaus et al. (2020) apply this idea to insurance decisions, showing that narrow framing can help explain observed risk-management choices. Furthermore, Kahneman and Lovallo (1993) argue that decision-makers often evaluate risky decisions in isolation, which can lead to excessive risk aversion because a single risky decision may appear less attractive than it would if it were evaluated together with other risks. This thesis therefore distinguishes between broad framing and narrow framing.

Under broad framing, the fertiliser contract is evaluated as part of the farmers overall farm profit. The farmer's utility is therefore evaluated over total winter wheat profit, including yield risk, output-price risk, fertiliser price risk and the cost and payoff of the contract. In this framing, the contract is treated as one component of a broader farm risk-management strategy.

Under narrow framing, the same contract is evaluated as a stand-alone financial decision. Rather than considering total farm profit, the farmer focuses only on the gain or loss generated by the contract relative to buying fertiliser later on the spot market. This means that the premium paid for the contract and the payoff received when fertiliser prices exceed the strike price become central to the evaluation.

This distinction is important because the two framings change what the farmer evaluates. Under broad framing, the fertiliser contract is only one part of total farm risk, so its effect may be small compared with yield and output-price risk. Under narrow framing, the farmer looks only at the contract itself, making the direct contract costs and payoffs more important. This may help explain why farmers do not always adopt risk-management instruments, even when such instruments appear beneficial from a broader risk-management perspective.

3.3. Conceptual model of fertiliser procurement under price risk

Fertiliser purchase decisions are made under multiple sources of uncertainty, as fertiliser is typically bought before final production outcomes and revenues are known. As a result, the decision can be viewed as a risk-management problem.

Three sources of risk are particularly relevant in this context. First, input-price risk refers to uncertainty about fertiliser prices between the planning stage and the point of purchase. Second, output-price risk arises from uncertainty about crop prices, which directly affects farm revenue. Third, yield risk reflects uncertainty in production outcomes caused by weather conditions, pests, diseases, and other production shocks.

In practice, a farmer may either postpone fertiliser purchase and buy later on the spot market or secure the fertiliser price in advance through a forward contract. Each alternative involves a trade-off between flexibility and certainty. Delaying the purchase may allow the farmer to benefit from future price declines, but it also exposes the farm to the risk of higher input costs. By contrast, locking in a price through a forward contract reduces input-price uncertainty for the contracted purchase, but it may also create dissatisfaction if the market later moves in a more favourable direction.

To evaluate fertiliser price-risk management in the Swedish context, this thesis builds on the framework by Spada et al. (2026). The economic model and contract design are kept largely unchanged to allow comparison with the original report, while the production context is adapted to Swedish winter wheat production. The model represents a farmer who produces winter wheat using nitrogen fertiliser as the main input. At time t_0 the crop choice is made, and the farmer is assumed to know the standard fertiliser requirement for the season and must decide how to procure this input under price uncertainty. The expected profit (π) is defined as revenue minus fertiliser cost:

$$\pi = p_w y(N) - p_N N (5)$$

Here p_w is the output price, $y(N)$ is expected yield, p_N is the fertiliser price and N is the fertiliser quantity.

3.4. Adjusted contract

The behaviourally adjusted contract is designed to protect the farmer against fertiliser price increases above a chosen threshold. It works by introducing a maximum fertiliser price, while still allowing the farmer to benefit if market prices fall below this threshold. By paying a premium, the farmer receives this price protection. If the fertiliser spot price at time t_1 exceeds threshold k the contract generates a payoff:

$$I = \max\left(p_{N,1} - k, 0\right) (6)$$

Here I is the insurance payoff, $p_{N,1}$ is the fertiliser spot price at time t_1 and k is the farmer specific threshold price. If the fertiliser price remains at or below the threshold the payoff is zero. The premium Γ is defined as the discounted expected value of the contract payoff:

$$\Gamma = E(I)e^{-rT} (7)$$

Where $E(I)$ is the expected value of the contract payoff, r is the risk-free rate and T is the delivery time. The purpose of this contract is to cap fertiliser cost while preserving the possibility of benefiting from lower market prices.

The behaviourally adjusted contract is evaluated against two standard contract choices. One option is to wait until shortly before application and buy fertiliser on the spot market $p_{N,1}$. This exposes the farmer to uncertainty because the future spot price is unknown. The other option is to enter a forward contract at time t_0, which fixes the fertiliser price for delivery at a later date. The forward price is given by:

$$f = p_{N,0} e^{-rT} (8)$$

Where $p_{N,0}$ is the fertiliser spot price at time t_0, r is the risk-free rate and T is the delivery time. In the model, transaction costs are not considered. This includes information gathering expenses, commissions and any additional costs related to entering a forward contract. Forward contracting is therefore treated as costless to enter.

3.5. Profit function under broad and narrow framing

The evaluation of the fertiliser price-risk management alternatives depends on whether the decision is framed broadly as part of total farm profit or narrowly as a stand-alone decision. In both cases, the contract specific payoff is first defined relative to buying fertiliser later on the spot market.

For the forward contract, the farmer commits to a fixed fertiliser price f. The gain or loss from the forward contract (Π_F) depends on whether the realised spot price of fertiliser, p_N, is higher or lower than the forward price. The per-unit payoff from the forward contract is therefore:

$$\Pi_F = f - p_N (9)$$

The value of the adjusted contract (Π_I) depends on if the payoff from the price ceiling (I) is greater or smaller than the premium paid. Therefore, it is calculated as the payoff minus the premium paid (Γ).

$$\Pi_I = I - \Gamma (10)$$

Under broad framing, the farmer evaluates the contract as part of total winter wheat profit. Profit per hectare is therefore defined as:

$$\pi_{BF} = p_w y(N) - p_N N + \Pi_i N (11)$$

where p_w is the wheat price, $y(N)$ is yield as a function of nitrogen, p_n is the fertiliser spot price, N is the quantity of fertiliser and Π_i is the per-unit payoff from $i \in \{0, F, I\}$. These are the no contract, forward contract and then the adjusted contract.

Under narrow framing, the farmer evaluates only the financial outcome of the contract, rather than total farm profit. The narrow-framed payoff per hectare is therefore:

$$\pi_{NF} = \Pi_i N (12)$$

where $\Pi_i N$ is the contract outcome times the quantity of nitrogen. In this case, yield, wheat revenue, and the baseline fertiliser cost are excluded from the evaluation. The farmer focuses only on the gain or loss generated by the contract relative to buying fertiliser at the spot price.

4. Data

4.1. Data overview

This section describes the two data blocks used in the analysis. First, the production side of the analysis is based on simulated winter wheat yield data from the EPIC-IIASA crop model, which are used to estimate nitrogen-yield relationships in each region included in the analysis. Second, observed fertiliser and wheat price data are used to estimate the relationship between input and output price risk. The two data blocks are then combined in the Monte Carlo simulation, where simulated yields, fertiliser prices, wheat prices, and contract payoffs determine profit outcomes under different contracts, framings, and behavioural theories.

4.2. Simulated yield data

Simulated yield data was obtained from the European version of the EPIC crop model, EPIC-IIASA (Balkovič et al. 2013). EPIC is a crop model that simulates crop growth and yield under different weather, soil, and management conditions, including fertiliser application, tillage and irrigation. The European implementation has been used to simulate regional crop yields for major European crops, including winter wheat.

Since the objective of this thesis is to examine whether the attractiveness of the adjusted fertiliser price contract differs across Swedish regions, the simulated yields are aggregated to the NUTS 2 level rather than analysed at individual simulation-unit level. NUTS 2 regions are suitable for comparing regions within Sweden because they are part of the EU's standardized territorial classification for regional statistics. Eurostat (n.d.) defines NUTS 2 as basic regions used for regional policy analysis, while NUTS 3 consists of smaller regions intended for more specific diagnoses. Therefore, NUTS 2 provides a useful balance between regional detail and broader comparability across Sweden. The regions shown in table 1 are the ones included in the analysis except for central and upper Norrland. These regions are selected because they represent areas where winter wheat production is agronomically relevant in Sweden.

Table 1. NUTS2 regions Sweden

NUTS 2 code	NUTS 2 region	NUTS 3 regions
SE01	Stockholm	SE010 Stockholm
SE02	Eastern Central Sweden	SE021 Uppsala; SE022 Södermanland; SE023 Östergötland; SE024 Örebro; SE025 Västmanland
SE09	Småland and the Islands	SE091 Jönköping; SE092 Kronoberg; SE093 Kalmar; SE094 Gotland
SE04	Southern Sweden	SE041 Blekinge; SE044 Skåne
SE0A	Western Sweden	SE0A1 Halland; SE0A2 Västra Götaland
SE06	Northern Central Sweden	SE061 Värmland; SE062 Dalarna; SE063 Gävleborg
SE07	Central Norrland	SE071 Västernorrland; SE072 Jämtland
SE08	Upper Norrland	SE081 Västerbotten; SE082 Norrbotten

The dataset contains simulated winter wheat yields under different nitrogen application rates, management practices, and weather scenarios. Table 2 provides an initial overview of the relationship between nitrogen and simulated winter wheat yields before estimating the production function. Across all regions, mean simulated yield increases with higher nitrogen application rates, indicating a positive relationship between nitrogen input and yield.

Table 2. Summary statistics for yield by region and nitrogen application rate

Region	Nitrogen rate	Mean	SD	Median	MAD	Min	Max	N
SE01	10	1.26	1.21	0.56	0.67	0.11	4.11	8,190
SE01	50	2.13	2.06	1.10	1.46	0.11	6.02	32,760
SE01	100	3.02	2.94	1.56	2.15	0.11	7.73	32,760
SE01	250	6.30	5.21	8.55	5.10	0.11	13.92	40,950
SE02	10	1.29	1.26	0.46	0.51	0.11	5.48	6,510
SE02	50	2.16	2.10	1.19	1.59	0.11	7.09	26,040
SE02	100	3.05	2.98	1.54	2.12	0.11	8.79	26,040
SE02	250	6.34	5.23	8.86	4.68	0.11	13.88	32,550
SE04	10	1.25	1.27	0.40	0.42	0.11	5.05	12,950
SE04	50	2.15	2.10	1.14	1.52	0.11	6.79	51,800
SE04	100	3.06	3.00	1.68	2.32	0.11	8.99	51,800
SE04	250	6.50	5.36	9.04	4.74	0.11	14.91	64,750
SE06	10	1.32	1.29	0.63	0.77	0.11	5.78	8,330
SE06	50	2.15	2.09	0.89	1.15	0.11	7.10	33,320
SE06	100	3.00	2.95	1.21	1.63	0.11	9.27	33,320
SE06	250	6.01	4.92	8.67	3.81	0.11	13.54	41,650
SE09	10	1.41	1.44	0.42	0.46	0.11	6.82	11,550
SE09	50	2.26	2.22	1.11	1.48	0.11	8.02	46,200
SE09	100	3.14	3.09	1.36	1.84	0.11	9.76	46,200
SE09	250	6.38	5.29	8.73	5.18	0.11	15.35	57,750
SE0A	10	1.30	1.31	0.51	0.59	0.11	6.82	14,280

SE0A	50	2.19	2.13	1.08	1.44	0.11	8.37	57,120
SE0A	100	3.09	3.02	1.40	1.91	0.11	10.30	57,120
SE0A	250	6.38	5.26	8.97	4.57	0.11	15.47	71,400

Note: The table reports summary statistics for simulated winter wheat yield at selected nitrogen application rates. Yield is measured in tonnes per hectare. Nitrogen rate is measured as kg N per hectare. MAD = median absolute deviation.

The descriptive statistics for the simulated wheat yield data show substantial variation across management practices, weather conditions, and regions. The simulations include variation in nitrogen application, water management, crop rotations, tillage practices, residue management, and weather scenarios across six Swedish NUTS2 regions. Dry-matter yields were converted to economic yields assuming a grain moisture content of 12%. The weather data include both historical simulations and future climate scenarios under low and high emission scenarios.

Mean simulated yields range from 3.62 t/ha in Northern Central Sweden to 5.07 t/ha in Southern Sweden. At first glance, these mean values appear relatively low compared with expected wheat yields. However, this should be interpreted in light of the high standard deviations observed across all regions, as well as the wide range between minimum and maximum simulated yields. These results suggest that the simulations capture a broad set of production conditions, including very low-yielding outcomes under unfavourable combinations of management and weather scenarios. In addition, the median values reported in Table 1 are more consistent with expected yield levels, indicating that the lower mean values may be influenced by extreme low-yield scenarios.

4.3. Fertiliser and wheat price data

Fertiliser price data were provided by Lantmännen and originate from Bloomberg. The dataset contains market prices for Calcium Ammonium Nitrate (CAN) representative for Northern Europe. These prices represent regional Northern European markets, as more regionalized fertiliser price series were not available. The fertiliser data are available in both SEK and EUR at weekly frequency from 2016 onwards. In the analysis SEK are used to represent what farmers observe more accurately. However, due to a gap in the fertiliser price series between 28 February 2023 and 28 April 2023, observations after 28 February 2023 are excluded from the empirical analysis to maintain a continuous price series.

Wheat price data were also provided by Lantmännen. The dataset includes MATIF wheat prices for the nearest futures contract, reported in both EUR and SEK. These series follow the same frequency structure as the fertiliser prices, with weekly observations. The final price dataset combines fertiliser and wheat prices at the same frequency and data range, which can be seen in Figure 1. This data is used to characterize the joint dynamics of input and output price risk.

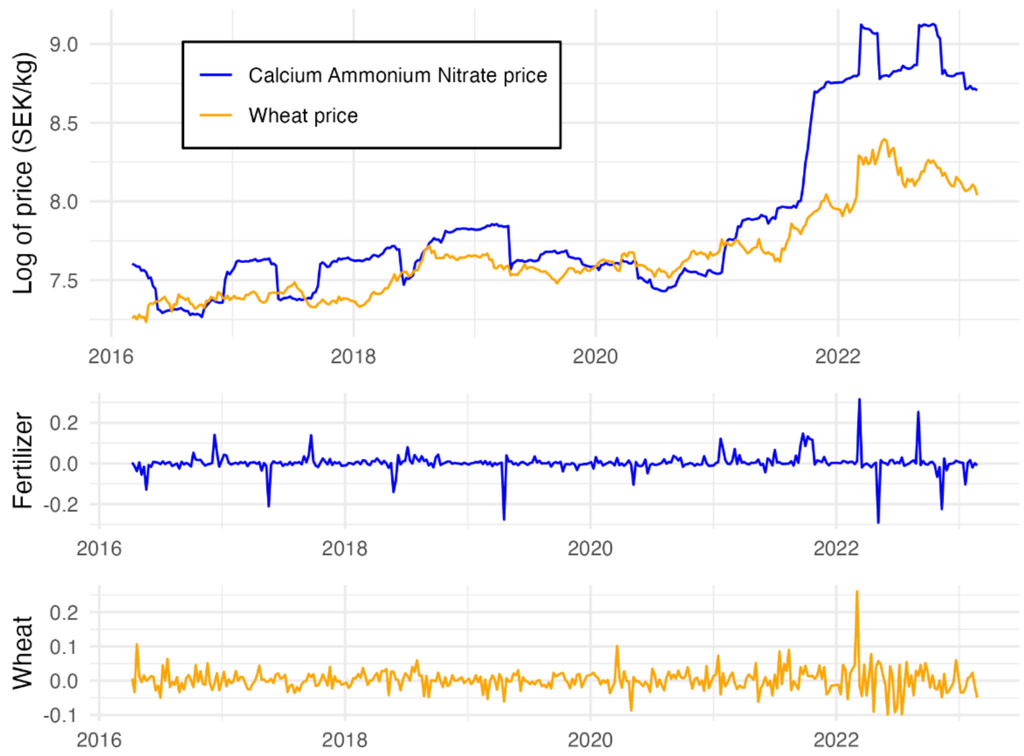

Figure 1. CAN and wheat log of prices Mar 2016-Feb 2023

A limitation of the price data is that fertiliser prices are observed only at the Northern European market level, rather than at a more regional level for Sweden. A similar limitation applies to the wheat price series, as these prices are used as a proxy for the spot prices faced by farmers. The analysis therefore assumes that these market prices capture the relevant variation in fertiliser price risk.

5. Methodology

To evaluate the attractiveness of behaviourally adjusted fertiliser price contracts, the analysis proceeds in four steps. First, the nitrogen-yield relationship is estimated to represent regional production conditions and yield risk. Second, wheat and fertiliser price dynamics are modelled using a QVAR-copula approach. Third, the adjusted fertiliser contract is priced using simulated fertiliser price outcomes. Finally, yields, prices and contract payoffs are combined in a Monte Carlo simulation and evaluated under EUT and CPT, using both broad and narrow framing.

5.1. Production function

The estimated statistical relationship between nitrogen and yield is derived from a production function based on the approach from Just and Pope (1979). This approach is suitable because it separates the effect of nitrogen on expected yield from its effect on yield variability. Traditional production functions often imply that any input that increases expected output also increase the output variance. However, this assumption can be restrictive because many inputs in agriculture, such as pesticides and irrigation, may reduce production risk. The Just and Pope production function separates the effect of inputs on mean output from their effect on output variance. The general model can be written as:

$$y = f(N) + h^{\frac{1}{2}}(N)\varepsilon (13)$$

where $f(N)$ determines the expected output, while $h^{\frac{1}{2}}(N)$ represents standard deviation and $h(N)$ determines the output variance. This lets an input increase in expected yield without necessarily increasing expected variance.

Furthermore, a square-root production function is used to model the nonlinear relationship between nitrogen input and yield. By including both $N^{1/2}$ and N, the marginal productivity of nitrogen is allowed to vary with the input level, making it possible to capture decreasing marginal productivity. The production function is estimated using lmrob, a robust regression estimator. This follows Finger and Hediger (2008), who show that both the functional form and estimation method can affect production function estimates. They find that the square-root specification performs well for their simulated yield data, while robust regression reduces the influence of extreme observations and may lower the economic costs associated with misspecification compared with least squares estimation. In the specification below $f(N)$ denotes yield, N is nitrogen fertiliser and X is a vector of control variables. If $\beta_1 > 0$ and $\beta_2 < 0$ the function will exhibit diminishing marginal productivity.

$$f(N) = \beta_0 + \beta_1 N^{\frac{1}{2}} + \beta_2 N + \gamma X + \varepsilon (14)$$

After estimating the expected yield function, the residuals are used to measure deviations between observed and predicted yields. Since the focus is on the size of these deviations rather than whether they are positive or negative, the residuals are transformed into absolute values ($\left|\hat{e}\right| = \left|y - \hat{y}\right|$) (Finger & Schmid 2008). These absolute residuals are then used as a proxy for yield variability in the second-stage regression. The estimated relationship is interpreted as an indication of how nitrogen application is associated with production risk.

$$h^{\frac{1}{2}}(N) = \left|\hat{e}\right| = \beta_0 + \beta_1 N^{\frac{1}{2}} + \beta_2 N + \gamma X + \varepsilon (15)$$

In the equation above, $h^{\frac{1}{2}}(N)$ represents yield variability, measured by the absolute residual $\left|\hat{e}\right|$ from the expected yield function. The nitrogen variables $N^{1/2}$ and N are included to test relationship between nitrogen and yield variability.

5.2. Price simulations

The next step is to simulate fertiliser and wheat prices based on historical price data. The purpose of the simulation is to generate a wider set of possible price scenarios than those observed in the historical sample. Historical data show only one realized price path, even though many alternative price paths could have occurred under the same underlying market conditions. By simulating prices, the analysis can account for a broader range of possible outcomes, including extreme price movements that are particularly relevant for risk management.

To generate simulated price outcomes, a two-step QVAR-copula approach is used, following Li and Chavas (2023). First, a Quantile Vector Autoregression (QVAR) model is used to estimate the marginal distributions of fertiliser and wheat price changes across different quantiles. Second, a copula function is applied to link these marginal distributions and construct their joint distribution. This joint distribution is then used to simulate correlated fertiliser and wheat price outcomes.

A standard VAR model describes average price dynamics but may fail to capture asymmetric behaviour in the tails of the price distribution. This is important because fertiliser price-risk management is particularly concerned with adverse price movements. Estimating price dynamics at different quantiles allows the response of fertiliser and wheat prices to differ between low, median, and high price-change states (Koenker & Xiao 2006). This is particularly important in agricultural commodity markets, where extreme price movements and responses to shocks play are important in risk assessment and decision-making (Li & Chavas 2023).

Following the QVAR-copula approach of Li and Chavas (2023) and its application to fertiliser and wheat prices in Spada et al. (2026), fertiliser and wheat price dynamics are first represented as a general autoregressive process:

$$p_t = \begin{bmatrix} p_{N,t} \\ p_{w,t} \end{bmatrix} = \begin{bmatrix} g_N(P_{t-1}) \\ g_w(P_{t-1}) \end{bmatrix} (16)$$

where p_t is the vector of current price changes, $p_{N,t}$ is the fertiliser price change, $p_{w,t}$ is the wheat price change and $P_{t-1} = (p_{t-1}, \dots, p_{t-n})$ contains lagged observations of fertiliser and wheat price changes. The functions $g_N(\cdot)$ and $g_w(\cdot)$ describe how current fertiliser and wheat price changes depend on previous values. Next the marginal distributions are estimated using the QVAR model:

$$F_N(p_N|P_{t-1}) = Prob[g_N(P_{t-1}) \leq p_N](17)$$
$$F_w(p_w|P_{t-1}) = Prob[g_w(P_{t-1}) \leq p_w](18)$$

where F_N describes the marginal distribution of fertiliser price changes and F_w describes the marginal distribution of wheat price changes. These marginal distributions show how each price series behaves separately. However, modelling the marginal distributions separately is not sufficient, because farm profit depends on the combination of fertiliser and wheat prices in each simulated outcome. The analysis is therefore interested in the joint distribution of fertiliser and wheat price changes:

$$F(p|P_{t-1}) = Prob[g(P_{t-1}) \leq p](19)$$

Where $F(p|P_{t-1})$ is the conditional joint distribution of fertiliser and wheat price changes and p is a possible joint price-change outcome containing both p_N and p_w. This equation describes the probability of different fertiliser and wheat price changes occurring together, conditional on past price changes. A copula is therefore used to combine the marginal distributions into a joint distribution, allowing simulated fertiliser and wheat prices to remain correlated.

$$F(p|P_{t-1}) = C[F_N(p_N|P_{t-1}), F_w(p_w|P_{t-1})](20)$$

The copula $C(\cdot)$ links the fertiliser and wheat marginal distributions into a joint distribution (Nelsen, 2006). This allows fertiliser and wheat price changes to be simulated jointly rather than independently. The copula therefore models the dependence structure between the two price-series. This is necessary because fertiliser and wheat prices jointly determine farm profit. For example, a fertiliser price increase has different implications depending on whether wheat prices also increase or remain low. Modelling the two price-series independently would ignore this dependence and could therefore generate unrealistic price scenarios for the Monte Carlo simulation.

5.3. Adjusted contract

The adjusted contract is treated as a fertiliser price ceiling. The contract is assumed to cover the period from the planting decision in autumn to fertiliser application in spring. The contract gives compensation only when the simulated fertiliser price at maturity exceeds the chosen strike price. In that case, the payoff is equal to the price difference above the strike price, otherwise the payoff is zero. The contract premium is calculated using a burn analysis, meaning that the payoffs from all simulated price paths are averaged and discounted back to the decision date using a 3% risk-free interest rate. The same procedure is applied to several strike prices, making it possible to compare contracts that offer different degrees of protection against high fertiliser prices (Spada et al. 2026).

$$\Gamma = \frac{1}{n}\sum_{i=1}^{n} I_i e^{-rT} \quad (21)$$

In the equation above, Γ is the contract premium, n is the number of simulations, I_i is the payoff from the adjusted contract in simulation i, r is the risk-free rate and T is the contract duration.

5.4. Economic decision model and behavioural preference assumptions

The simulated yield outcomes, wheat and fertiliser price dynamics, and contract costs are combined in the economic decision model to evaluate the effect of fertiliser price-risk management on farmer welfare. The analysis compares outcomes under two decision framings. Following Koszegi and Rabin (2006), the reference point under CPT for broad framing is set equal to expected profit, since reference-dependent preferences are assumed to depend on expectations about outcomes. Under narrow framing, the reference point is set to zero because the contract is evaluated as a stand-alone gain or loss.

The simulated profit distributions are evaluated using Expected Utility Theory (EUT) and Cumulative Prospect Theory (CPT). For the EUT specification, absolute risk aversion is represented by δ. Following the framework from Spada et al. (2026), δ is varied between 0.00001 and 0.001, where lower values represent less risk-averse farmers and higher values represent more risk-averse farmers. Since the analysis uses SEK, δ is converted from the EUR scale to the SEK scale.

For CPT, the behavioural parameters are based on empirical estimates for Swedish farmers. Rommel et al. (2023) find that the Swedish farmers in their sample display risk aversion in the gain domain, some degree of loss aversion, and probability distortion. The estimated CPT parameters for the Swedish sample are $\sigma = 0.329$, $\lambda = 1.352$, and $\gamma = 0.552$. Here, σ captures the curvature of the value function, λ captures loss aversion, and γ captures probability weighting. These values are therefore used as the standard assumption for the CPT specification. Alternative parameter values are also used as sensitivity analysis.

6. Results

The following section presents the results from this analysis of the simulation for Swedish farmers and assess whether the adjusted contract could be a viable option to manage input price risk. First, the estimated production and yield variation functions are reported to show how nitrogen application affects both expected wheat yield and production risk. Second, the price dynamics of CAN and wheat are presented, including the simulated price distributions used in the Monte Carlo analysis. Third, the pricing of the adjusted fertiliser contract is reported for different strike prices. Finally, the contract alternatives are evaluated under Expected Utility Theory and Cumulative Prospect Theory, using both broad and narrow decision framing.

6.1. Production and variation function

Estimates for the production function are presented in Table 3. The model includes controls for water and land management practices. Across all Swedish regions, nitrogen application shows a nonlinear relationship with simulated wheat yield. The positive coefficient for square root fertiliser and the negative coefficient for fertiliser suggests that nitrogen is associated with higher yields, but at a decreasing marginal rate.

Table 3. Regional production function estimates

Variable	SE0A	SE01	SE02	SE04	SE06	SE09
Constant	4.749*** (0.036)	1.172*** (0.068)	1.681*** (0.074)	4.559*** (0.043)	1.808*** (0.044)	2.098*** (0.076)
Fertiliser square root	0.23*** (0.007)	0.691*** (0.013)	0.697*** (0.014)	0.447*** (0.008)	0.377*** (0.011)	0.693*** (0.014)
Fertiliser	-0.017*** (0)	-0.031*** (0.001)	-0.033*** (0.001)	-0.028*** (0)	-0.024*** (0.001)	-0.029*** (0.001)
Irrigation	10.793*** (0.019)	2.71*** (0.024)	2.451*** (0.025)	1.146*** (0.015)	9.913*** (0.029)	5.881*** (0.03)
Minimum tillage	-11.619*** (0.034)	-1.562*** (0.027)	-1.596*** (0.027)	-1.676*** (0.015)	-0.158*** (0.044)	-3.599*** (0.042)
Tillage R00	-3.905*** (0.013)	-1.894*** (0.022)	-2.392*** (0.024)	-4.456*** (0.014)	-1.385*** (0.019)	-2.683*** (0.027)
Tillage R30	-3.88*** (0.014)	-2.634*** (0.022)	-3.011*** (0.024)	-4.411*** (0.014)	-1.436*** (0.025)	-3.6*** (0.026)
Tillage R60	-3.969*** (0.014)	-2*** (0.021)	-2.451*** (0.023)	-4.254*** (0.013)	-1.502*** (0.023)	-3.139*** (0.025)
Tillage R90	-3.756*** (0.014)	-2.663*** (0.022)	-3.036*** (0.023)	-4.352*** (0.013)	-1.362*** (0.024)	-3.645*** (0.026)
Num. obs.	265320	203364	168932	352692	150220	222612
R^2	-0.371	0.04	0.013	-0.22	-0.353	0.192
Adj. R^2	-0.371	0.04	0.013	-0.22	-0.353	0.192

Note: Standard errors are shown in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4 presents the estimated variation functions for the Swedish regions. The dependent variable is the absolute residual from the production function, which is used as a proxy for yield variability. Across all regions, the coefficient for square root fertiliser is positive, while the coefficient for fertiliser is negative. This suggests that the association between nitrogen application and simulated yield variability may change over the fertiliser range. The estimated marginal effect declines as nitrogen application increases, but the practical importance of this pattern depends on the size of the predicted change over realistic nitrogen levels. Therefore, the results should be interpreted as indicative of a possible pattern in the simulated data, rather than as strong evidence that additional nitrogen substantially changes production risk.

Table 4. Regional variation function estimates

Variable	SE0A	SE01	SE02	SE04	SE06	SE09
Constant	-0.578*** (0.011)	-2.622*** (0.018)	-2.872*** (0.021)	-2.24*** (0.016)	-0.918*** (0.011)	-2.803*** (0.015)
Fertiliser square root	0.371*** (0.002)	0.725*** (0.003)	0.79*** (0.004)	0.744*** (0.003)	0.511*** (0.003)	0.708*** (0.003)
Fertiliser	-0.025*** (0)	-0.031*** (0)	-0.037*** (0)	-0.042*** (0)	-0.031*** (0)	-0.03*** (0)
Irrigation	0.867*** (0.006)	0.48*** (0.007)	0.33*** (0.008)	-0.007 (0.006)	0.615*** (0.007)	-0.142*** (0.007)
Minimum tillage	-1.142*** (0.01)	-0.258*** (0.007)	-0.301*** (0.008)	-0.428*** (0.005)	-0.424*** (0.01)	1.512*** (0.009)
Tillage R00	0.939*** (0.004)	1.614*** (0.006)	1.684*** (0.007)	1.274*** (0.005)	0.829*** (0.005)	1.976*** (0.005)
Tillage R30	1.03*** (0.004)	1.102*** (0.006)	1.234*** (0.007)	1.2*** (0.005)	0.812*** (0.006)	1.424*** (0.005)

Tillage R60	0.992***	1.312***	1.405***	1.258***	0.767***	1.535***
	(0.004)	(0.006)	(0.007)	(0.005)	(0.006)	(0.005)
Tillage R90	1.115***	0.942***	1.072***	1.151***	0.829***	1.286***
	(0.004)	(0.006)	(0.007)	(0.005)	(0.006)	(0.005)
Num. obs.	265320	203364	168932	352692	150220	222612
R^2	-0.453	0.102	0.004	-0.333	-0.421	0.021
Adj. R^2	-0.453	0.102	0.004	-0.333	-0.421	0.021

Note: Standard errors are shown in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

6.2. QVAR estimations

To model the dynamics of wheat and fertiliser price changes, the marginal distributions are estimated using a QVAR model. Before interpreting the QVAR results, the linear VAR results are used to provide an initial overview of the average short-run relationship between fertiliser and wheat price changes. In the fertiliser price equation in Table 5, both lagged fertiliser price changes and lagged wheat price changes are statistically significant. This suggests that fertiliser price changes show some persistence and that previous wheat price movements are associated with current fertiliser price movements. In the wheat price equation in Table 6, neither lagged fertiliser price changes nor lagged wheat price changes are statistically significant. This indicates that short-run wheat price changes are not well explained by the included lagged price variables.

The QVAR estimates in table 5 show that the relationship differs across the fertiliser price-change distribution. Lagged fertiliser price changes are positive and statistically significant at the median and at the 0.7 quantile. This suggests that fertiliser price changes show some persistence at the median and at moderately high positive changes. Lagged wheat price changes are statistically significant only at the 0.9 quantile. This indicates that wheat price movements are associated with fertiliser price changes mainly during large positive fertiliser price changes. Overall, the results suggest nonlinear fertiliser price dynamics, with stronger cross-price dependence in the upper tail of the fertiliser price-change distribution.

Table 5. VAR and QVAR estimates for fertiliser

Variable	VAR	QVAR 0.1	QVAR 0.3	QVAR 0.5	QVAR 0.7	QVAR 0.9
Constant	0.002 (0.002)	-0.014*** (0.003)	-0.004*** (0.001)	0.002*** (0.001)	0.007*** (0.001)	0.030*** (0.008)
Fertiliser price, lag 1	0.106** (0.052)	-0.019 (0.051)	0.015 (0.011)	0.033*** (0.011)	0.034* (0.021)	0.103 (0.269)
Wheat price, lag 1	0.284*** (0.075)	0.022 (0.079)	0.032 (0.020)	0.023 (0.023)	0.045 (0.031)	0.286*** (0.088)
Num. obs.	352	352	352	352	352	352
R^2 / pseudo R^2	0.054	-0.140	-0.016	0.012	0.010	-0.337
Adj. R^2	0.048					

*Note: Standard errors are shown in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.*

The QVAR estimates for wheat price changes in Table 6 show that lagged fertiliser price changes are negative and statistically significant at the 0.1 and 0.3 quantiles. This suggests that previous fertiliser price increases are associated with lower wheat price changes in the lower part of the wheat price-change distribution.

Table 6. VAR and QVAR estimates for wheat

Variable	VAR	QVAR 0.1	QVAR 0.3	QVAR 0.5	QVAR 0.7	QVAR 0.9

Constant	0.002 (0.002)	-0.031*** (0.003)	-0.011*** (0.002)	0.001 (0.002)	0.014*** (0.002)	0.036*** (0.004)
Fertiliser price, lag 1	-0.022 (0.037)	-0.110* (0.057)	-0.079*** (0.012)	-0.016 (0.063)	0.036 (0.027)	0.044 (0.048)
Wheat price, lag 1	-0.036 (0.054)	-0.120 (0.084)	-0.007 (0.050)	-0.027 (0.055)	-0.045 (0.054)	-0.123 (0.113)
Num. obs.	352	352	352	352	352	352
R^2 / pseudo R^2	0.003	-1.149	-0.185	0.001	-0.149	-1.155
Adj. R^2	-0.003					

*Note: Standard errors are shown in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.*

6.3. Copula estimations

The linear copula estimation shows a positive and statistically significant relationship between the conditional quantile positions of wheat and fertiliser price changes. This indicates that higher fertiliser price-change quantiles are associated with higher wheat price-change quantiles.

The quantile copula estimates also show positive and statistically significant dependence across all reported quantiles. This suggests that the positive dependence between wheat and fertiliser price changes is present throughout the distribution, although its strength varies across quantiles. The dependence is strongest around the middle of the distribution and weaker in the upper tail.

Table 7. Copula estimates of dependence between fertiliser and wheat price changes

Dependent var Wheat price distribution	**Linear**	**Q0.1**	**Q0.3**	**Q0.5**	**Q0.7**	**Q0.9**
Intercept	0.384***	0.018	0.147***	0.326***	0.528***	0.848***

	(0.030)	(0.022)	(0.037)	(0.062)	(0.057)	(0.036)
Fertiliser price distribution	0.228***	0.181***	0.294***	0.352***	0.304***	0.094**
	(0.053)	(0.063)	(0.078)	(0.109)	(0.089)	(0.047)
Observations	352	352	352	352	352	352

Notes: Standard errors are shown in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

6.4. Contract pricing

For the pricing of the adjusted contract 1000 price paths are simulated over 52 time periods (1 year). Table 8 presents the estimated premiums for the adjusted fertiliser contract at different strike prices. The results show that the premium decreases as the strike price increases. This is expected because a lower strike price provides protection over a wider range of fertiliser price outcomes and therefore leads to a higher expected payout. At the lowest strike price of 6.105 SEK/kg, the premium is 0.271 SEK/kg, while at the highest strike price of 6.994 SEK/kg, the premium decreases to 0.050 SEK/kg. This illustrates the trade-off between protection and cost. Lower strike prices offer stronger protection against fertiliser price increases, but require a higher premium, whereas higher strike prices are cheaper but only provide protection against more extreme price increases.

Table 8. Strike prices and option premium

Strike price	Option premium
6.105	0.271
6.243	0.210
6.403	0.155
6.641	0.099
6.994	0.050

Notes: Strike prices expressed in SEK/kg

6.5. EUT broad framing

Under EUT broad framing, contracts are evaluated as part of total farm profit. The results show that the forward contract is the most attractive alternative across all Swedish regions and all levels of absolute risk aversion. Table 9 presents the CE for Southern Sweden and the entire table for all regions can be seen in Appendix 1. The results indicate that, when the fertiliser price decision is evaluated as part of total farm profit, fixing the fertiliser price through a forward contract provides the highest certainty equivalent under EUT. The certainty equivalent under the forward contract is consistently higher than under no contract, indicating that fixing the fertiliser price provides value across all risk-aversion categories in this specification.

The adjusted contracts provide smaller and less consistent gains. In many low-risk-aversion cases, the adjusted contracts slightly increase the certainty equivalent relative to no contract. However, in several regions and at higher levels of risk aversion, the adjusted contracts perform worse than no contract. This suggests that the protection offered by the adjusted contract does not always compensate for the premium paid. Compared with the forward contract, the adjusted contracts are therefore less attractive under EUT broad framing.

As expected, certainty equivalents decrease as the absolute risk aversion parameter increases, while risk premiums increase. This reflects the stronger utility penalty that more risk-averse farmers place on uncertain profit outcomes. The level of the certainty equivalent also differs substantially between regions, indicating regional heterogeneity in simulated profitability and risk exposure. Overall, the broad-framing EUT results suggest that fertiliser price risk management can increase certainty equivalents, but the forward contract performs better than the adjusted price-ceiling contracts in this specification.

Table 9. EUT under broad framing Southern Sweden

Risk aversion	No contract	Forward	AC1	AC2	AC3	AC4	AC5
Very low	12853.69	13031.59	12856.95	12855.98	12855.91	12855.20	12854.22
Low	11547.16	11723.00	11550.10	11549.47	11549.64	11549.17	11548.23
Central	9913.99	10087.27	9916.53	9916.34	9916.80	9916.62	9915.73

High	-3151.39	-2998.59	-3151.97	-3148.74	-3145.93	-3143.72	-3144.19
Very high	-19483.10	-19355.90	-19487.59	-19480.08	-19474.34	-19469.16	-19469.10

Note: The table reports certainty equivalents under broad framing for Southern Sweden.

6.6. EUT narrow framing

Because narrow framing only considers the contract payoff, and the same price data are used for all regions, the narrow-framing results do not vary across regions. Under this framing, the contracts are evaluated as stand-alone investments relative to a reference point of zero. Therefore, only the forward contract and the adjusted contracts are evaluated. In this setting, the forward contract performs poorly, with negative certainty equivalents across all levels of risk aversion. This suggests that fixing the fertiliser price is unattractive when evaluated in isolation, because the farmer gives up the possibility of benefiting from lower future fertiliser prices.

The adjusted contracts perform better than the forward contract under narrow framing. At very low, low, and central levels of risk aversion, all adjusted contracts generate positive certainty equivalents, while the forward contract shows negative values. At the high level of risk aversion, some adjusted contracts remain positive, but at the very high level all adjusted contracts become negative. This suggests that the adjusted contracts are more attractive than the forward contract when the contract is evaluated in isolation, because they allow the farmer to benefit from lower fertiliser prices while still limiting exposure to high prices. Among the adjusted contracts, AC1 provides the strongest protection because it has the lowest strike price, and it performs best from very low to high risk aversion. However, at the very highest level of risk aversion, AC5 has the least negative certainty equivalent, likely because it has a lower premium rather than because it offers stronger protection.

Table 10. EUT under narrow framing

Risk aversion	**Forward**	**AC1**	**AC2**	**AC3**	**AC4**	**AC5**
Very low	-178.54	3.27	2.23	2.11	1.36	0.38

Low	-179.06	3.04	2.04	1.97	1.26	0.33
Central	-179.71	2.75	1.80	1.79	1.14	0.27
High	-184.95	0.41	-0.10	0.32	0.19	-0.19
Very high	-191.49	-2.51	-2.47	-1.51	-0.99	-0.77

Note: The table reports certainty equivalents under narrow framing. Values are rounded to two decimals. Higher values indicate more attractive alternatives. AC = adjusted contract.

6.7. CPT broad framing

In the CPT broad-framing case, contracts are evaluated as part of total farm profit. Using the standard CPT parameter assumptions, the results in Table 11 show that the forward contract generally performs best in all regions except Northern Central Sweden (SE06), where AC1 performs best. This suggests that a contract with a price ceiling can be attractive in some cases. However, the improvements are small and not consistent across regions, indicating that the adjusted contract may be less attractive because the premium is paid with certainty, while the payoff from the contract is uncertain.

Table 11. CPT under broad framing

Region	No	Forward	AC1	AC2	AC3	AC4	AC5
SE0A	-6.15	-5.92	-6.25	-6.23	-6.21	-6.11	-6.23
SE01	-6.70	-6.49	-6.57	-6.56	-6.71	-6.58	-6.65
SE02	-7.32	-7.13	-7.38	-7.39	-7.39	-7.30	-7.36
SE04	-6.90	-6.59	-6.82	-6.88	-6.73	-6.73	-6.88
SE06	-6.34	-6.25	-6.14	-6.23	-6.29	-6.24	-6.42
SE09	-6.47	-6.38	-6.46	-6.52	-6.48	-6.42	-6.45

Note: The table reports CPT values for each contract alternative under broad framing. Standard behavioural assumptions are $\alpha = 0.329$, $\lambda = 1.352$, and $\gamma = 0.552$. Higher values indicate more attractive alternatives.

The sensitivity analysis considers alternative levels of loss aversion, curvature, and probability weighting and can be seen in Appendix 2. The results indicate that the adjusted contracts can become more attractive under some behavioural assumptions, particularly in Northern Central Sweden and in a few cases in Småland and the Islands. However, across most regions and sensitivity scenarios, the forward contract still provides the highest CPT value. Overall, the CPT framework under broad framing suggests that the adjusted contract can be attractive in some Swedish regions, but the forward contract remains the most robust alternative across regions and behavioural assumptions.

6.8. CPT narrow framing

For CPT under narrow framing, using the standard parameter assumptions, the adjusted contracts perform better than the forward contract. However, all contracts have negative CPT values under the standard assumptions. This means that the adjusted contracts are preferred relative to the forward contract, but they are not attractive in absolute terms. The sensitivity analysis shows that CPT parameter choices affect the contract ranking. Lower loss aversion makes the adjusted contracts more attractive, and when $\lambda = 0.5$, AC1 to AC4 generate positive CPT values. By contrast, stronger loss aversion makes all contract values more negative. Overall, the adjusted contracts generally perform better than the forward contract, but their relative ranking depends on the assumed CPT parameters.

Table 12. CPT under narrow framing

Scenario	Forward	AC1	AC2	AC3	AC4	AC5
Standard	-3.74	-1.92	-1.98	-2.06	-2.13	-2.16
Alpha = 0.1	-0.62	-0.56	-0.64	-0.73	-0.91	-1.09
Alpha = 0.5	-13.35	-4.45	-4.28	-4.14	-3.70	-3.23
Lambda = 0.5	0.00	0.73	0.61	0.45	0.26	-0.05
Lambda = 2	-6.58	-3.93	-3.95	-3.96	-3.95	-3.77
Gamma = 0.4	-4.06	-1.72	-1.67	-1.69	-1.59	-1.60
Gamma = 0.7	-3.63	-2.22	-2.37	-2.49	-2.67	-2.67

Note: The table reports CPT values under narrow framing. Standard assumptions are $\alpha = 0.329$, $\lambda = 1.352$, and $\gamma = 0.552$. Higher values indicate more attractive alternatives. AC = adjusted contract.

Overall, the results suggest that regional yield differences influence expected outcomes, profit variability, and the valuation of the contract alternatives. However, the relative ranking of the alternatives is more strongly affected by the assumed decision frame and behavioural model. In particular, the adjusted contract appears less attractive under broad framing, where it is evaluated as part of total production profit, but becomes more favourable under narrow framing, where the fertiliser price outcome is evaluated separately. This indicates that the attractiveness of the adjusted fertiliser contract is driven more by how the decision is framed than by regional yield differences alone.

7. Discussion

The main finding from this analysis is that regional differences in Sweden play a limited role in explaining the attractiveness of adjusted fertiliser contracts. Although regions differ in yield levels and production risk, these differences do not appear to drive the relative ranking of the contract alternatives. Instead, contract attractiveness depends more strongly on the framing of the purchasing decision. Under narrow framing, where the contract is evaluated as a separate investment, the adjusted contract generally appears more attractive relative to the forward contract because it protects against large increases in fertiliser prices while still allowing the farmer to benefit if prices fall. Under broad framing, where the contract is evaluated as part of total farm profit, the forward contract performs better in most cases. This suggests that the adjusted contract can reduce fertiliser price risk, but that the value of this protection may be too small to compensate for the premium once yield risk and wheat price risk are included.

This highlights why decision framing matters for the interpretation of contract attractiveness. When the fertiliser decision is evaluated in isolation, the direct payoff structure of the adjusted contract becomes important. Compared with the forward contract, the adjusted contract provides more flexibility because it protects against high fertiliser prices while still allowing the farmer to benefit from lower prices. However, this flexibility comes at the cost of a premium. When the same contract is evaluated as part of total farm profit, the value of this flexibility may be too small to compensate for the premium, especially when yield risk and wheat price risk are also included. Therefore, the adjusted contract may perform less well under broad framing, even though it offers more favourable payoff characteristics under narrow framing.

This could also explain why there is not a large difference between the regions. Although there is some regional variation, the overall results remain relatively consistent across regions. This suggests that price movements, contract design, and the premium have a larger influence on the ranking of contracts than regional yield differences. Because the same fertiliser and wheat price simulations are used for all regions, the regional differences in the model come mostly from yield levels and production risk. However, these differences are not large enough to substantially change the relative ranking of the contract alternatives. This does not mean that regional production conditions are unimportant. Rather, it suggests that, within this model, regional differences affect the level of profits and risk exposure, while contract attractiveness is more strongly shaped by contract design, behavioural assumptions and the framing of the decision.

When comparing the results of this thesis with the original study by Spada et al. (2026), the findings are not identical, although they point in a similar direction. In Spada et al. (2026), the adjusted contract was mainly attractive under EUT when the decision was broadly framed. The forward contract likely performed poorly because it removed the natural hedge between fertiliser and wheat prices. In this thesis, the broad-framing results differ. The forward contract generally performs better, while the adjusted contract appears more attractive when the fertiliser decision is evaluated separately under narrow framing.

Despite these differences, both studies point to a similar overall conclusion. The attractiveness of fertiliser price-risk management tools depends strongly on how the decision is framed and on the assumed behavioural preferences. Both studies suggest that managing fertiliser price risk alone may have limited effects when the decision is evaluated as part of total farm risk. In this sense, the results of this thesis do not simply contradict Spada et al. (2026), but show that the performance of the behaviourally adjusted contract is sensitive to context and model assumptions.

Furthermore, this thesis uses EUT and CPT as the main decision-making frameworks for evaluating the contracts. Although CPT has empirical support and has been shown to explain farmers behaviour better than EUT in lottery-choice settings (Bocquého et al. 2014; Rommel et al. 2023), other behavioural frameworks may also be relevant. One example is tri-reference point theory, which suggests that farmers may evaluate risky outcomes relative to multiple reference points rather than a single benchmark (Mattsson 2025). Under broad framing, the contract may not only be evaluated relative to expected profit, but also relative to minimum acceptable income levels, usual profit expectations, or aspirational profit targets. Although these reference points are not tested directly in this thesis, tri-reference point theory highlights that the attractiveness of risk-management tools may depend on other behavioural factors and assumptions not fully captured by EUT and CPT.

This connects back to the broader question of why financial risk-management tools often have low adoption rates in agriculture. Standard economic theory suggests that risk management tools should be attractive to risk-averse farmers, but actual adoption remains limited (Assefa et al. 2017; Spada et al. 2026). One explanation is that farmers do not evaluate these tools only according to expected profit and variance reduction. Instead, adoption may depend on how the decision is framed, how the premium is perceived, which reference points are relevant and whether the instrument is useful in relation to the farm’s broader risk profile. This means that designing more attractive risk-management tools requires a better understanding of farmers behavioural preferences and decision processes. The results of this thesis support this view by showing that the same contract can appear attractive depending on the assumed decision framework and framing.

7.1. Limitations

These results should be interpreted with some caution because the study has several limitations. First, the yield data are based on simulations from the EPIC crop model rather than observed farm-level data. Although EPIC provides realistic estimates of crop yields, the simulated data may not fully capture actual farm conditions in the Swedish regions.

Second, the price data used in this study are proxies for the prices Swedish farmers face. The CAN price data are representative of Northern European fertiliser markets, while the wheat prices are based on MATIF futures prices. These price series are relevant for Swedish farmers, but they are not the same as the actual farm-level prices paid or received by individual farmers. Ideally, the analysis would use farm-level or region-specific Swedish prices, because basis risk can differ between regions. Basis risk refers to the risk that the price used in the model does not move perfectly together with the price faced by the farmer. For example, a MATIF wheat futures price may increase, but the price received by a Swedish farmer may increase by a smaller or larger amount depending on local market conditions, transport costs and quality differences. This means that the model captures general market price risk, but may not fully capture the local price risk faced by individual farmers.

Third, the behavioural parameters used for EUT and CPT are based on values from previous studies using abstract lottery gambles, rather than being estimated directly for Swedish farmers in the specific fertiliser contract decision analysed in this thesis. In addition, the same parameters are applied across all regions, meaning that potential heterogeneity in farmers risk preferences is not captured. While the sensitivity analysis tests alternative parameter values, the results should still be interpreted as outcomes under assumed preferences rather than as direct predictions of actual adoption behaviour.

7.2. Policy implications

The results of this thesis have some policy implications, although these should be interpreted with caution given the limitations discussed above. A central finding is that framing and behavioural assumptions influence the perceived attractiveness of different risk-management tools. At the same time, the regional focus of the analysis shows that risk-management decisions should also be understood in relation to local production conditions. This makes advisory services especially relevant, since advisory firms often operate regionally and can account for differences in production conditions across Sweden. Increased support for such services could therefore help farmers evaluate input-price contracts alongside other risk-management tools, such as yield insurance or output-price hedging, rather than promoting adjusted fertiliser contracts as a stand-alone solution. In this sense, adjusted fertiliser contracts may be more useful as one component of a broader risk-management strategy than as an isolated tool.

Future research could build on this thesis in several ways. First, further studies could examine whether alternative designs of fertiliser contracts would be more attractive to farmers. Second, future research could use observed farm-level data and region-specific price data to better capture the actual production and price risks faced by Swedish farmers. This would be especially useful for analysing basis risk and local differences in market conditions. Finally, future research could extend the analysis by including other behavioural assumptions that may better explain farmers decision-making. For example, alternative frameworks such as tri-reference point theory could be used to examine whether farmers evaluate risk-management tools relative to multiple reference points, such as minimum acceptable income, expected profit, or aspirational profit levels.

8. Conclusion

This thesis evaluated whether behaviourally adjusted fertiliser price contracts can be attractive risk-management tools for Swedish winter wheat producers, and whether their attractiveness differs across Swedish regions, decision-making frameworks, and framing assumptions. The thesis extends the framework of Spada et al. (2026) by applying it to a regional Swedish context. The analysis compares several Swedish regions with different yield levels and production risk. This makes it possible to assess whether regional production conditions change the relative attractiveness of the contract alternatives.

The results show that regional differences in Sweden affect expected profit levels and production risk, but they do not substantially change the relative ranking of the contract alternatives. Instead, the attractiveness of the contracts is mainly determined by how the decision is framed and by the behavioural assumptions used to evaluate the contracts. Under broad framing, where the fertiliser decision is evaluated as part of total farm profit, the forward contract generally performs better than the adjusted contract. This suggests that the additional flexibility provided by the adjusted contract does not compensate for the premium paid. Although the adjusted contract allows farmers to benefit from lower fertiliser prices while limiting exposure to high prices, this advantage is generally too small relative to its cost when yield risk and wheat price risk are included in the overall profit calculation. Under narrow framing, where the fertiliser-price outcome is evaluated separately, the adjusted contract becomes more favourable relative to the forward contract. This is because the forward contract protects against higher prices but also locks the farmer into a fixed price, while the adjusted contract allows the farmer to benefit from lower prices and still limits exposure to high prices. However, this relative advantage does not necessarily mean that the adjusted contract is attractive in absolute terms, since the value of this flexibility must still compensate for the premium paid.

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Popular science summary

Farmers face uncertainty from changing weather, yields and volatile input and output prices. This thesis studies whether behaviourally designed fertiliser price contracts can help Swedish winter wheat farmers manage fertiliser price risk.

The analysis compares these contracts with buying fertiliser on market price or locking in the price through a forward contract. It uses simulated Swedish winter wheat yields and price simulations based on historical wheat and fertiliser price data.

The results show that regional differences in Sweden affect profit levels and production risk, but they do not strongly change which contract performs best. Instead, the results are mainly shaped by the choice of decision framework and whether the contract is evaluated as part of total farm profit or as a stand-alone decision. Overall, the adjusted contracts are not clearly better than simpler alternatives for Swedish winter wheat farmers.

Appendix 1

Region	Risk aversion	nc	fc	ac_1	ac_2	ac_3	ac_4	ac_5
SE0A	Very low	9448	9607	9451	9450	9450	9449	9448
SE0A	Low	9062	9221	9065	9065	9065	9063	9063
SE0A	Central	8579	8739	8583	8582	8583	8581	8581
SE0A	High	4717	4882	4725	4725	4727	4727	4726
SE0A	Very high	-110	60	-97	-96	-94	-92	-92
SE01	Very low	10894	11053	10897	10896	10896	10895	10895
SE01	Low	9821	9977	9822	9822	9822	9821	9821
SE01	Central	8480	8633	8479	8479	8479	8478	8479
SE01	High	-2251	-2122	-2267	-2266	-2264	-2264	-2259
SE01	Very high	-15664	-15566	-15700	-15697	-15692	-15691	-15680
SE02	Very low	10586	10745	10589	10588	10588	10586	10586
SE02	Low	9088	9246	9090	9089	9089	9088	9087
SE02	Central	7216	7372	7217	7216	7216	7214	7214
SE02	High	-7763	-7618	-7770	-7770	-7772	-7775	-7774
SE02	Very high	-26487	-26355	-26503	-26503	-26506	-26511	-26508
SE04	Very low	12873	13032	12876	12875	12875	12874	12874
SE04	Low	11566	11723	11569	11569	11569	11568	11567
SE04	Central	9932	10087	9935	9935	9935	9935	9934
SE04	High	-3138	-2999	-3137	-3134	-3131	-3129	-3129
SE04	Very high	-19476	-19356	-19476	-19470	-19463	-19458	-19457
SE06	Very low	2671	2830	2674	2673	2673	2672	2671
SE06	Low	1933	2090	1935	1934	1934	1933	1933
SE06	Central	1010	1165	1011	1010	1010	1009	1009

SE06	High	-6370	-6233	-6380	-6381	-6381	-6379	-6376
SE06	Very high	-15596	-15481	-15619	-15620	-15619	-15615	-15609
SE09	Very low	15539	15698	15542	15542	15541	15540	15540
SE09	Low	14653	14811	14655	14655	14654	14653	14653
SE09	Central	13545	13701	13546	13546	13546	13545	13545
SE09	High	4679	4826	4675	4676	4676	4677	4679
SE09	Very high	-6404	-6268	-6414	-6412	-6410	-6407	-6403

Notes: Values are certainty equivalents under Expected Utility Theory and broad framing. Risk-aversion categories correspond to increasing values of δ. Values are rounded to the nearest SEK/ha.

Appendix 2

Region	Scenario	nc	fc	ac_1	ac_2	ac_3	ac_4	ac_5
SE0A	Standard Assumptions	-6.10	-5.92	-6.22	-6.14	-6.21	-6.10	-6.07
SE0A	Alpha = 0.1	-0.33	-0.32	-0.35	-0.34	-0.34	-0.33	-0.33
SE0A	Alpha = 0.5	-42.05	-40.89	-42.33	-42.16	-42.38	-42.03	-41.89
SE0A	Lambda = 0.5	3.23	3.36	3.11	3.19	3.12	3.22	3.26
SE0A	Lambda = 2	-13.20	-12.98	-13.31	-13.24	-13.30	-13.20	-13.16
SE0A	Gamma = 0.4	-7.99	-7.80	-8.21	-8.03	-8.19	-7.97	-7.89
SE0A	Gamma = 0.7	-4.93	-4.75	-5.00	-4.97	-4.99	-4.94	-4.92
SE01	Standard Assumptions	-6.68	-6.49	-6.67	-6.66	-6.63	-6.75	-6.68
SE01	Alpha = 0.1	-0.34	-0.32	-0.35	-0.34	-0.33	-0.35	-0.34
SE01	Alpha = 0.5	-48.51	-47.57	-48.30	-48.41	-48.31	-48.70	-48.40
SE01	Lambda = 0.5	4.06	4.23	4.08	4.09	4.12	4.00	4.07
SE01	Lambda = 2	-14.86	-14.64	-14.85	-14.84	-14.81	-14.92	-14.85
SE01	Gamma = 0.4	-8.55	-8.23	-8.57	-8.50	-8.42	-8.68	-8.57
SE01	Gamma = 0.7	-5.54	-5.39	-5.53	-5.54	-5.52	-5.57	-5.54
SE02	Standard Assumptions	-7.43	-7.13	-7.27	-7.37	-7.36	-7.41	-7.36
SE02	Alpha = 0.1	-0.36	-0.34	-0.35	-0.36	-0.36	-0.36	-0.35

SE02	Alpha = 0.5	-55.58	-53.95	-54.80	-55.18	-55.15	-55.39	-55.29
SE02	Lambda = 0.5	3.97	4.23	4.11	4.01	4.03	3.97	4.03
SE02	Lambda = 2	-16.09	-15.77	-15.93	-16.03	-16.02	-16.08	-16.03
SE02	Gamma = 0.4	-9.52	-9.04	-9.22	-9.45	-9.42	-9.53	-9.40
SE02	Gamma = 0.7	-6.11	-5.92	-6.04	-6.09	-6.08	-6.11	-6.09
SE04	Standard Assumptions	-6.83	-6.59	-6.77	-6.85	-6.76	-6.75	-6.89
SE04	Alpha = 0.1	-0.30	-0.28	-0.30	-0.30	-0.30	-0.29	-0.30
SE04	Alpha = 0.5	-52.11	-50.80	-51.79	-52.10	-51.77	-51.73	-52.35
SE04	Lambda = 0.5	4.24	4.45	4.30	4.22	4.30	4.32	4.17
SE04	Lambda = 2	-15.25	-14.99	-15.19	-15.26	-15.18	-15.16	-15.31
SE04	Gamma = 0.4	-8.96	-8.58	-8.85	-9.01	-8.84	-8.80	-9.09
SE04	Gamma = 0.7	-5.50	-5.33	-5.47	-5.50	-5.46	-5.46	-5.52
SE06	Standard Assumptions	-6.29	-6.25	-6.10	-6.19	-6.17	-6.26	-6.36
SE06	Alpha = 0.1	-0.33	-0.33	-0.32	-0.33	-0.33	-0.33	-0.34
SE06	Alpha = 0.5	-44.97	-44.52	-44.03	-44.37	-44.30	-44.74	-45.16
SE06	Lambda = 0.5	3.90	3.91	4.11	4.02	4.04	3.94	3.84
SE06	Lambda = 2	-14.04	-13.97	-13.87	-13.95	-13.93	-14.02	-14.11
SE06	Gamma = 0.4	-8.08	-8.14	-7.72	-7.91	-7.86	-8.04	-8.23
SE06	Gamma = 0.7	-5.20	-5.10	-5.13	-5.16	-5.15	-5.19	-5.23
SE09	Standard Assumptions	-6.50	-6.38	-6.40	-6.46	-6.50	-6.44	-6.49
SE09	Alpha = 0.1	-0.31	-0.30	-0.30	-0.30	-0.31	-0.30	-0.31

SE09	Alpha = 0.5	-47.77	-47.05	-47.33	-47.60	-47.69	-47.52	-47.69
SE09	Lambda = 0.5	3.94	4.02	4.05	3.99	3.95	4.01	3.96
SE09	Lambda = 2	-14.45	-14.29	-14.34	-14.40	-14.44	-14.38	-14.43
SE09	Gamma = 0.4	-8.55	-8.39	-8.29	-8.41	-8.52	-8.38	-8.51
SE09	Gamma = 0.7	-5.22	-5.09	-5.18	-5.21	-5.22	-5.20	-5.21

Notes: Values are CPT values under broad framing. The standard assumptions are $\alpha = 0.329$, $\lambda = 1.352$, and $\gamma = 0.552$. α captures value-function curvature, λ captures loss aversion, and γ captures probability weighting.

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